CZECH TECHNICAL UNIVERSITY IN PRAGUE

DOCTORAL THESIS STATEMENT

Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Ing. Marian Kněžek

RISK MANAGEMENT IN ELECTRICITY SALES OF POWER PRODUCER

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Candidate: Ing. Marian Kněžek
Department of Economics, Management and Humanities
Faculty of Electrical Engineering of the CTU in Prague
Address: Zikova 4, 166 27 Prague 6

Supervisor: Prof. Ing. Oldřich Starý, CSc.
Department of Economics, Management and Humanities
Faculty of Electrical Engineering of the CTU in Prague
Technická 2, 166 27 Prague 6

Supervisor-Specialist: Ing. Miroslav Vítek, CSc.
Department of Economics, Management and Humanities
Faculty of Electrical Engineering of the CTU in Prague
Address: Zikova 4, 166 27 Prague 6

Opponents:

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Those interested may get acquainted with the doctoral thesis concerned at the Dean Office of the Faculty of Electrical Engineering of the CTU in Prague, at the Department for Science and Research, Technická 2, Praha 6.

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Chairman of the Board for the Defence of the Doctoral Thesis
in the branch of study Business Management and Economics
Faculty of Electrical Engineering of the CTU in Prague
Technická 2, 166 27 Prague 6.

1. CURRENT SITUATION OF THE STUDIED PROBLEM

Most of the electricity markets in the industrial countries have been deregulated. Electricity turned into an asset freely traded in the market place. Power producers became a part of electricity market and as well as traders tend to sell produced electricity in the most favourable way to increase its profit. Power producers are exposed to electricity market risk through the trading of electricity and electricity related derivatives as well as commodities associated with electricity production. Electricity prices are highly unpredictable and volatile. High volatility reflects lower liquidity of the market products and hence the maturity of the market. Investments in trading activities and risk management expertise are soaring as companies become aware of market risks in their businesses. To ensure the rules of free market the demand side (customers) also has the option to choose electricity supplier.

The risks in general are potential unknown threats which flow from extraordinary situations. In the financial markets there are all kinds of stochastic and deterministic models and their modifications and combinations to address these risks. However the field of risk management in the energy sector especially related to power producers is still in its infancy. Risk Management is responsible for establishing and maintaining appropriate risk framework across the trading process. Risk Management has no responsibility for trading activities and must remain independent of trading. Risk Management also takes responsibility for the measurement and management of counterparty credit risk, finance risk, compliance with policies and procedures and ensuring adequate IT systems are available. The elementary introduction into risk management, with summary chapters on market risk, credit risk and operational risk is worked out by Jorion in Value-at-Risk: The New Benchmark for Managing Financial Risk [21]. There is a brief discussion of risk management in banking, investment management, pension funds, and corporate settings. The overall risk management in deregulated electricity market including description of products and risk management techniques is provided by Knezek in [23], [24]. Another perspective with focus on electricity market is described by Rickenlund [31] and Hung-Po [17] with number of questions for further development. Besides the articles and researchers described above a full insight overview has been provided by Leppard in [29], which provide clear understanding of energy risk management issues, illustrates the purpose of energy derivatives, and evaluates their benefits and weaknesses.

The theory and practice of financial and non-financial linear derivative instruments used in the matured financial markets are described in general in [5], and in more detail in [1], [4], [9]. Application of energy linear derivatives are covered in [13] by Geman. Typical approved instruments used in the electricity market are Forwards and Futures. There might be available other instruments however their usage is currently quite rare.

The theory and practice of financial non-linear derivative instruments used in the matured financial markets are published in general in [33] and in more detail by Jilek in [17], [19], [20]. Application of different types of energy options including exotic options, spread and basket options, digital option, quanto options and real options is examined in detail by Wengler in [36]. Different perspective is provided by Spinler, Huchzermeier and Kleindorfer in [34], where authors focus on options contracts that enable risk-sharing between the trading partners- buyer and seller.

Valuation of different kind of options through either geometric Brownian motion or mean reverting processes is introduced in [9] by Deng, Johnson and Sogomonian. The valuation results have been used in turn to construct real options. The application of their research in practice has been left for future researches.

Another approach has been used by Eydeland and Geman in [12]. Option prices are examined through production based approach, where they estimate base load price, forward prices of marginal fuel, expected load conditional on the information at time and “power stack”. In the work they list a number of issues they would need to address and therefore this work is more like a discussion paper left for future researches.

The most common option pricing model used is Black-Scholes formula [1]. Many empirical tests have shown that the Black–Scholes price is "fairly close" to the market prices. Option value is based on the above mentioned factors and the general theoretical assumptions of market behaviour.

Power producers have tremendous competitive advantage opposed to electricity traders to produce electricity. In this respect power producers have in their hands possibilities to generate higher revenues with lower risks. However this potential opportunity has not been fully utilised. Power producers have high knowledge of running the business in terms of generating electricity and selling it to the market either through bilateral contracts or through organised power exchanges however the higher profitable part of the business – sales to portfolios of individual customers has been partially overtaken by electricity traders whose business is based on cheaper purchase and higher price sale.

In order to achieve this marginal resale traders have sophisticated tools to assess the electricity consumption of its customers’ portfolio for certain period of time in advance. In the light of the above the number of electricity traders increased several times in last couple of years as electricity trading became highly profitable business. However this business bears risks as traders might not be able to purchase cheaper electricity on the market. Some of their contracts binding them to sale the electricity to their customers for specified price and these contracts might become loss making. In contrast power producers would have possibility to produce the electricity themselves and reduce or eliminate these losses.

2. AIMS OF THE DOCTORAL THESIS

Motivations

Banks have established standard products that are developed to the perfection. The question is whether these products could be transformed into the electricity market given the fact that the underlying asset is completely different, has different features in terms of production and utilization. On the other hand it can be argued that power producers have in some ways better position than banks in the financial market as they are able to generate underlying asset in contrast with banks that are not able to print money. Analysing this advantage with applied financial products in the electricity market we might get huge opportunities.

In order to identify market opportunities we need to have a look on the electricity market participants and their roles, product, responsibilities and regulation. In this respect it is necessary to look at the power producer from three perspectives:

- look at the power producer as a standalone entity,
- compare power producer's role in the electricity market with the role of the banks in the financial markets,
- identify products that are used for years in the financial market that can be used in the current electricity markets.

The objective of this work will be to identify these electricity market opportunities and find the effective way for the utilization of these opportunities.

Goals of the dissertation thesis

The aim of this work is to bring new ideas and or directions to the current power producers practice. The main goal would be to evaluate possibility of power producer to provide typically financial market products to its customers that are usually provided by the financial institutions. Especially, whether the power producers are able to effectively write electricity market options and take over this role from the banks.

In order to achieve this goal we need to understand current power producer's situation. It is questionable, what is the right measure for the power producers to evaluate its portfolio. There are different contracts agreed with counterparties for wide range of period of time. Some of the contracts have expired while others are still running or have not yet been utilised. Due to this fact the power producers' portfolios get into different positions all the time (closed historical, closed future or open position). The single unitary measure would be much of help to value the portfolio. The measure should be also able to evaluate new products e.g. options the same way. Another goal of this doctoral thesis therefore will be to determine the measure for the power producers' portfolios evaluation.

Power producers may also consider opportunity to trade the electricity on its own desk the same way like electricity market traders do. These speculations on electricity prices movements may get the portfolio into unfavourable position. It would be questionable, what is the maximum risk the electricity producer is willing to face and how to measure the risk. Last goal therefore will be to determine measure the risk of the open position.

This work does not aim to compile findings and results of others university or consulting colleagues researches, thesis, reviews or analysis. Its main aim is to bring new views based on author's knowledge gained from the university and consulting and audit practices.

Hypotheses

In the light of the main goal above the main hypothesis will be that "Power producers are able to get into arbitrage and generate risk free profit through delta hedge based on self-issued option contracts and possibility to generate underlying electricity."

There are different kinds of measures of individual electricity portfolio positions. To create strong fundaments for the main hypothesis and in line with necessity to evaluate power producer's portfolio the sub-hypothesis needs to be determined: "Evaluation of the power producer's portfolio should be based on Gross Margin."

In case of proprietary trading the strengths and weaknesses of power producers need to be analysed. By trading on its own desk power producer gets into risky positions that may cause damage of immense size. The last sub-hypothesis will be: "The most suitable measure to evaluate risk of open position should be based on Value at Risk metrics."

3. WORKING METHODS

To test theoretical hypothesis established above a combination of different kind of methods will be utilised. The core of the thesis will be based on analogy and experiment as already established well known quantitative techniques used in the financial markets by banks will be analysed and applied to the electricity markets for power producers. It is questionable whether the patterns typical for the electricity markets represent any barriers in order to apply these methods in the electricity market:

- non-storability of electricity, production and consumption has to be perfectly synchronised so the demand and supply are all the time in balance,
- dependence on weather/seasonality (e.g. differences in consumption during the hot summer/cold summer/winter or long and short days),
- high volatility of the market prices,
- limited production capacity and its structure,
- …

The research was performed in four consecutive steps:

- Analysis of all relevant researches already performed in this area.
- Evaluation and usage of the previous researches in this thesis.
- Evaluation of the goals of the doctoral thesis and hypothesis related,
- Applicability of theory on the practical model.

Delta hedge - Black-Scholes formula and Taylor series

First goal relates to evaluation of possibility of power producer to provide typically financial market products to its customers that are usually provided by the financial institutions – power options.

There are few articles that deal with hedging strategy for power producers, however there is no article with the same or similar approach related to possibility of power producer to write options. Also term of Delta hedging is used for different things in these articles. In most of the articles authors are using word “delta” as a general term for a deviation. For example in [8] Bundalova, DeJong and VanDijken calls delta a difference between sales price of electricity futures and purchase price of fuel. While in this thesis it describes first derivative of Black-Scholes formula according to electricity price.

The only delta hedge with the same meaning is used in the article called Energy Modelling and Management of Uncertainty [12], where Eydeland and Geman says that the delta hedge in the electricity market cannot be implemented due to non-storability of the electricity as electricity has to be bought and kept for some time. The article does not describe this fact in detail and therefore it is hard to understand the reason to provide this statement. However this is strong statement which can be easily disproved. The trading with electricity prices is not about physical settlement and storability but about financial settlement. In this respect it does not really matter whether the electricity market participant actually has the physical power or facility to produce it. Further this thesis deals directly with power producer which can produce agreed amount of electricity at any time in its facility so the electricity is stored in its input, which is fuel (coal, gas, ...).

Delta hedging is a method of ensuring that the value of a portfolio of options will not fluctuate when the price of the underlying asset fluctuates. Delta hedging is based on combination of option pricing formula and Taylor series. The most common option pricing model used is Black-Scholes formula [1]. Many empirical tests have shown that option prices according to the Black–Scholes pricing formula are "fairly close" to the market prices. Using of Black-Scholes pricing formula was also argued in [31], where Pineda and Conejo says that due to non-storability of the electricity Black-Scholes pricing equation “is not generally a good method for pricing electricity derivatives”. The only argument they have is a link to [36], where Wu describes pricing of European options based on the fuzzy pattern of Black–Scholes formula. Wu’s paperwork is based on stock prices and does not relate to electricity market. Wu is trying to modify Black Scholes formula to implement jump diffusion model. Wu admits that even though his modification to the standard Black-Scholes formula gives slightly more accurate results, it boosts (as he says complicates) pricing model greatly. In this respect it is not applicable in practice and leaves this model in the theoretical area and provides reasonable argument that Black-Scholes model is still valid and mostly used option pricing tool in practice. Stochastic modelling of forward electricity prices and using of hedging strategies including analysis of temperature derivatives is published in [2] by brothers Benth and Koekebakker.

Delta hedge is based on application of Taylor series on first partial derivative of Black-Scholes model. It helps us to evaluate the amount of underlying asset needed to maintain neutral portfolio – Delta hedge, get power producer into arbitrage and generate risk free profit. By applying Taylor series on option delta we obtain options value approximation. This approximation allows effectively revaluate option contracts in the portfolio. This is convenient due to the high demand on IT solutions bearing in mind the amount of data that need to be processed.

Gross Margin

Gross Margin represents the sales revenues that company retains after incurring the direct costs associated with the production sold by the company. In this respect we would need to identify power producer's portfolio, divide it into positions and assess whether the Gross Margin is the right measure for the evaluation of the individual positions.

There are number of articles that relate to pricing in the wholesale electricity market. For example in [5] Borenstein examines marginal costing and divides firms into market makers as those who exercises market power when it reduces its output or raises the minimum price at which it is willing to sell output (its offer price) in order to change the market price and price taking firms as those who are taking price given in the market. This is usually typical for the monopoly or oligopoly markets. It might be also the case in the Czech Republic if the biggest producer CEZ is completely privatised. In this case the intervention of power exchange, independent system operator or government regulatory body is necessary to alter the operation of the wholesale electricity market. However as the price-taking firm still sells its output at the market price which is usually above the marginal production cost of all or almost all the production, price-taking firms can still cover their full costs, including their going-forward fixed costs of operation.

The competitiveness and the exercising of power in the electricity market would be above the scope of this thesis. After deep research of the scientific sources there were no articles that are focusing on the portfolio valuation of power producer from the trading perspective. There is a need to categorize market positions and use unitary measure for the business evaluation.

Value at Risk

Power producer is able to generate electricity. Due to this fact its risk of open position might be rather limited or eliminated depending on the strategy and risk appetite of the power producer. To evaluate the risk of open position, JP Morgan [22] developed RiskMetrics methodology called VaR (Value at Risk). VAR is a measure of the risk of a specific portfolio at a specified probability and over a specified time horizon in case of normal market trend. VAR takes into account fixed portfolio which is not changed within the defined period.

There are several books related to Value at Risk. The fundaments are explained in detail by Holton in [16] and by Jorion in [21]. These books are not market specific and deals with Value at Risk in general. An application of parametric models and Monte Carlo simulation in Value at Risk metrics has been introduced by Cheung and Powell in [9]. A positive part of this publication is its application in practice. The data used are from financial markets. Another application of Monte Carlo simulation on Value at Risk is described by Glasserman, Heidelberger and Shahabuddin in [14]. One of the most important results from their empirical study found is that market returns exhibit greater kurtosis and heavier tails than can be captured with a normal distribution.

According to Lehikoinen in [29] another approach for VAR calculation might be Extreme Value Theory which can capture extremities better than conventional probability distributions, as it concentrates on the observations that exceed certain limit. The attention is focused on the tail of the price distribution, which is the area where the VAR is estimated. The question is whether these so called fat tails is the main issue why the conventional probability distributions do not describe the pattern of the electricity market prices fluctuations. Another question is whether the Log-normal distribution could be used for the Value at Risk calculation at the fat tail area.

Analysis of Extreme Value Theory technique is even in more detail published by Gencay, Selcuk, Ulugulyagci in [14]. This research is based on stock market S&P500 and ISE indexes. As already mentioned in introduction financial markets are more developed and have different pattern than electricity markets. One of the main point will be that stock price can increase several times during a short period and remain on the same level for years, while electricity do not have such a huge jumps and always get back to an average price level in short time period.

Extreme Value Theory became evergreen for past ten years and there are number of authors like Paul Embrechts, Alexander McNeil, Richard Smith, Rüdiger Frey, Francois Longin, Hans Byström and Kimmo Lehikoinen that performed number of articles on this topic. These articles define EVT VAR which is modified Value at Risk technique described above for the extreme electricity market prices fluctuations.

As power producers have possibility to generate missing amount of electricity if they are in a short position or stop producing electricity if they are in the long position, they can always avoid rare situation of high electricity price movements. Due to this fact Extreme Value Theory seems to be redundant for power producers.

4. RESULTS

This thesis is based on analysis of current electricity market situation and examination of opportunity gaps found during the comparison of electricity markets with more matured financial markets and also comparison of strengths and weaknesses of power producers as opposed to the electricity market traders. This thesis provides unique directions to re-establish electricity markets and increase their efficiency.

In the introductory chapter I have defined three goals to be achieved in this research and come to the following results:

- Determine the proper measure for the power producers portfolio evaluation

  In connection with this goal I have hypothesized that: “Evaluation of the power producer’s portfolio should be based on Gross Margin.” In order to evaluate the portfolio I have divided power producer’s portfolio into several positions. The Gross Margin as a measure used for the valuation of power producer’s portfolio has been assessed as the most appropriate one. This part is worked out in chapter 3.

  The goal has been achieved and related hypothesis has been validated.

- Determine the possibility of power producer to trade the electricity on its own desk the same way like electricity market traders

  In connection with this goal I have hypothesized that: “The most suitable measure to evaluate risk of open position should be based on Value at Risk metrics.” The competitive advantage of power producers has been described in the chapter 2. The approach of trading electricity and the risk management strategy related including the evaluation of the open position based on Value at Risk was worked out in chapter 4 with references to risk management framework as described in chapter 2.

  The goal has been achieved and related hypothesis has been validated.

- Evaluate the possibility of power producer to provide typically financial market products like options to its customers that are usually provided by the financial institutions.

  In line with this goal I have hypothesized that: “Power producers are able to get into arbitrage and generate risk free profit through delta hedge based on self-issued option contracts and possibility to generate underlying electricity.” By using partial derivative of options value according to different variables I got Greeks modified for the electricity market. These Greeks helped me to evaluate the amount of underlying asset needed to maintain neutral portfolio – Delta hedge and verify the hypothesis that power producer is able to get into arbitrage and generate risk free profit. By-product of this thesis is that I have applied Taylor series [31] on these Greeks and obtained options value approximations. The valuation of options for large portfolios presents a trade-off between speed and accuracy, with the fastest methods relying on rough approximations and the most realistic approach – Black-Scholes – often too slow to be practical. In this respect Greeks approximations represent invaluable possibility for delta hedge neutral options portfolio revaluation with great accuracy within required time period. This can greatly reduce the time that would be otherwise needed. The application of all Greeks and their presentation on practical example gives a huge benefit of this thesis. This part is worked out in chapter 5.

The goal has been achieved and related hypothesis has been validated.

5. CONCLUSION

This work is in some aspects unique. It presents usage of proprietary trading, Greeks and delta hedge both hedging of the portfolio position and optimization of the portfolio position in the electricity market. It is based on application of theoretical mathematical models and techniques in practice. It also provides an overview of other important risk management issues in the electricity market and can be used as a basis for further work on this topic. This work might be helpful for the top management of the power producing companies as it helps to setup business strategy framework and establish Risk Management and Power Asset Liability Management functions governing the management of the risks and management of all positions across all of the trading activities. It gives a unique chance to find out directions to re-establish electricity markets and increase their efficiency.

Power producing companies can now optimize the sale of their production capacities with the objective of maximizing profit from wholesale electricity, financial instruments and supporting services.

Individual areas of this thesis have been presented on international student conferences on electrical engineering and published in peer-reviewed journal [24], [25], [26], [27], [28]. Some of the theses won several awards:

- 2nd place in CEZ competition for the best scientific and technical research
- 3th place awarded by Czech Technical University committee on 11th International Student Conference on Electrical Engineering.
- Award of main sponsor – General Electric on 11th International Student Conference on Electrical Engineering

Last but not least this doctoral thesis is based on diploma thesis which has been awarded by dean’s price.

As a by-product of the thesis has been performed a testing of probability distribution through Pearson’s chi-squared test. Even though none of the tested probability distribution gave us null hypothesis true, the closest results of the real electricity market prices to the empirical probability distribution were given by the log-normal distribution. These results are very valuable and present a strong fundament for researches to be performed in this area.

One of the main focus of the thesis was the applicability and implementation of suggested solutions in practice. Individual goals are not standalone goals that deal with selected part of the business but rather are connected and interdependent on the production facility. In this respect I have prepared an overview in relation to the implementation of the opportunities related to defined goals in practice. Proposed solutions described in the thesis solve the goals stated and are implementable in the practice in the form as described.

As stated in the introduction paragraph the aim of this thesis wasn't to compile findings and results of others university or consulting colleagues researches, thesis, reviews or analysis. But based on their findings, mathematical techniques and based on my experience and knowledge, of the electricity market and financial market I have been able to produce the thesis that will bring new ideas and directions in the current power producers market situation.

For better understanding of the topic described, individual chapters are supplemented by model calculations illustrating how to use the techniques, metrics and/or instruments in practice. In order to provide a complete overview of presented results in context I have created a comprehensive model, where individual parts of the thesis are presented.

List of literature used in the thesis statement

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List of candidate’s works relating to the doctoral thesis

Impacted Journals: -

Peer-reviewed Journals:

KNĚŽEK M.: Power Producer Risk Management, Acta Polytechnica 2008, Czech Technical University in Prague

Patents: -

Web of Science publications: -

Other publications:

KNĚŽEK M.: Řízení rizik na trhu s elektřinou, 10th International Student Conference on Electrical Engineering - Poster 2006, Czech Technical University in Prague

KNĚŽEK M.: Electricity Market Risk Management, 11th International Student Conference on Electrical Engineering - Poster 2007, Czech Technical University in Prague

KNĚŽEK M.: Power Producer Production Valuation, 12th International Student Conference on Electrical Engineering - Poster 2008, Czech Technical University in Prague

KNĚŽEK M.: Power Producer Risk Management, 17th International Student Conference on Electrical Engineering - Poster 2013, Czech Technical University in Prague

List of response / No response and reviews

10th International Student Conference on Electrical Engineering

- 2nd place in ČEZ competition of the best student’s scientific and technical project

11th International Student Conference on Electrical Engineering

- Award of main sponsor - **General Electric**
- **3rd place** - awarded by Czech Technical University committee

List of candidate’s works that is not related to the doctoral thesis

Impacted Journals: -

Peer-reviewed Journals: -

Patents: -

Web of Science publications: -

Other publications: -

ANOTACE

Práce pojednává o možnostech využítí hlavní komparativní výhody výrobce elektrické energie, kterou je výroba elektrické energie. Tato komparativní výhoda je dále analyzována ze tří úhlů pohledu:

- Analýzy výrobce elektřiny, jako samostatného,
- Porovnání role výrobce elektrické energie na trhu s elektřinou s rolí bank na finančních trzích,
- Identifikace produktů, které se využívají léta na finančních trzích a které mohou být využívány na stávajících trzích s elektřinou.

Tato analýza nám definuje nové obchodní příležitosti výrobců elektrické energie. Tyto příležitosti představují základní cíle disertační práce:

- Stanovení metodiky ohodnocení portfolia výrobce elektrické energie.

  V souvislosti s tímto cílem byla stanovena hypotéza: "Ohodnocení portfolia výrobce elektrické energie by mělo být založeno na hrubé marži." Aby bylo možné ohodnotit portfolio výrobce bylo nutné jej rozdělit na jednotlivé pozice. Výsledkem práce bylo zjištění, že hrubá marže se jeví jako nejvhodnější nástroj pro oceňování portfolia výrobce elektrické energie . Tato část je zpracována v kapitole 3.

  Cíle bylo dosaženo, související hypotéza byla potvrzena.

- Stanovení možností výrobce elektrické energie obchodovat s elektřinou na své vlastní riziko stejně jak obchodují obchodníci na trhu s elektřinou.

  V souvislosti s tímto cílem byla stanovena hypotéza: "Nejvhodnější způsob vyhodnocení rizika otevřené pozice by měl být založen na Value at Risk."" Konkurenční výhody výrobců elektrické energie byly popsány v kapitole 2. Způsob obchodování elektrické energie a s tím související strategie řízení rizik včetně ohodnocení otevřené pozice založené na Value at Risk byla zpracována v kapitole 4 s odkazy na rámec pro řízení rizik popsaný v kapitole 2.

  Cíle bylo dosaženo, související hypotéza byla potvrzena.

- Stanovení možností výrobce elektřiny vytvářet opce na elektrickou energii a převzít tuto roli u bank.

  V souvislosti s tímto cílem byla vytvořena hypotéza: "Výrobci elektrické energie jsou schopni vytvořit arbitráž a generovat zisk bez rizika prostřednictvím zajištění Delta na základě vlastních vydaných opčních kontraktů a možnosti vyrábět elektrickou energii." Aplikací parciálních derivací na hodnotou opcí podle různých proměnných bylo možné stanovit Greeks upravených pro trh s elektrickou energii. Tyto Greeks umožňují vyhodnotit množství podkladového aktiva – elektrické energie potřebné pro zachování neutrálního portfolia prostřednictví zajištění Delat a ověřit hypotézu, že výrobce elektrické energie je schopen vytvořit arbitráž a generovat bezrizikový zisk. Vedlejším produktem bylo vytvoření aproximačních vzorců na základě aplikace Taylorova rozvoje na Greeks. Tyto aproximace umožňují účinně přehodnotit hodnoty opčních kontraktů v portfoliu. To je výhodné vzhledem k vysoké nárokům na IT s ohledem na množství dat, které je třeba zpracovat. Tato část je zpracována v kapitole 5.

Cíle bylo dosaženo, související hypotéza byla potvrzena.

Definované cíle nepředstavují samostatné izolované okruhy výrobce elektrické energie, ale jsou propojeny a vzájemně závislé na výrobním zařízení výrobce.

Pro ilustraci výsledků práce a pro lepší pochopení jsou jednotlivé kapitoly doplněny o příklady výpočtu, které ilustrují užití dané techniky v praxi. Pro ucelený přehled souvislostí jsem vytvořil komplexní model v MsExcel formátu, jež je přiložen k disertační práci na CD.